Three Phase Controlled Rectifier Study in Terms of firing angle variations

Ali Akbar Motie Birjandi[1], Zahra Ameli[2],
[1] Electrical Department Shahid Rajayee Teacher Training University, Tehran, Iran
Email: motiebirjandi @ srttu.edu
[2] Electrical Department Shahid Rajayee Teacher Training University
Email: z_ameli@yahoo.com

***Abstract*—This paper introduce topology of three phase controlled rectifiers and proposed an accurate Statistical method to calculate their input current harmonic components, and calculate THD and harmonic currents with accurate simulation in various firing angles, then investigate influence of load variations in terms of firing angle variations on harmonic currents. Finally a harmonic current database of rectiûers is obtained in terms of firing angle and load variations.**

***Index Terms*—Harmonic, Three phase controlled rectifier, Firing angle**

I. Introduction

Harmonic is component of a sine wave with a periodic amount which the frequency of this is integer Multiple of the Fundamental wave. Harmonic In a power system Cause losses and depreciation in the transmission and distribution equipment and power consumers, so study and their control is essential. Appearance of semiconductor and nonlinear elements such as diode, Thyristor and so on and great use of them in the power system make new factor for development harmonic [1].

Already, use of nonlinear loads connected to distribution network, including multiple rectifiers is growing. Increase their number create a lot of problem in Electricity network. Some of this problems are Transformers and motors heating, Increasing current of parallel capacitors, Increasing current of Neutral wire in Four-wire three phase systems, destroy voltage shape and etc[2].

Three-phase six-pulse thyristor converters are the basic element in transmission system of Electrical energy. These converter because of their nonlinear Properties generate harmonic currents, which most of these currents cause series problems in system. The main features of multiple rectifier is the it's ability to Reduce distortion of Line current harmonics. This problem may be with set a phase shifting transformer. Because lose some of the low- order harmonic currents that produce with them. In general, at Higher number of pulses, line current distortion is lower [3]. rectifier Because of Growing use of this nonlinear converters and their harmonic problems.

This paper introduce topology of three phase controlled rectifiers and proposed an accurate Statistical method to calculate their input current harmonic components, and calculate THD and harmonic currents with accurate simulation in various firing angles, then investigate Effect of load variations in terms of firing angle variations on harmonic currents. Finally a harmonic current database of rectiûers is obtained in terms of firing angle and load variations.

II. Fourier Series and Power System Harmonics

Fourier Series: The primary scope of harmonics modeling and simulation is in the study of periodic, steady-state distortion.[3](c1.pdf)

A three phase controlled rectifier is shown in Fig. 1.

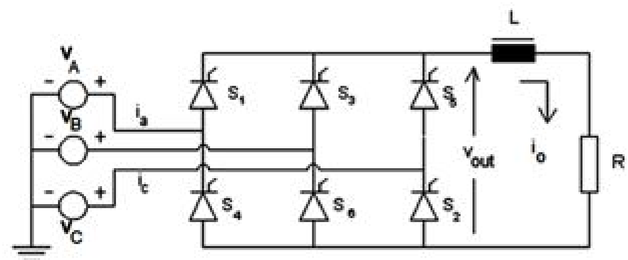

Figure 1. Three phase controlled rectifier

The RMS value of the nth harmonic of input current corresponding with the following relation:

$$I_n = \tfrac{1}{\sqrt{2}}\left(a_n^2 + b_n^2\right)^{1/2} = \frac{2\sqrt{2}\, I_a}{n\pi}\sin\frac{n\pi}{3} \tag{1}$$

The total RMS value of current is:

$$I_{rms} = (I_{1(rms)}^2 + I_{2(rms)}^2 + I_{3(rms)}^2 + \ldots + I_{n(rms)}^2)^{1/2} \tag{2}$$

Input current in the system is:

$$i_a = \frac{2\sqrt{3}}{\pi} I_d \begin{pmatrix} \sin(\omega t-\phi_1)+\frac{1}{5}\sin 5(\omega t-\phi_1)- \\ \frac{1}{7}\sin 7(\omega t-\phi_1)+\frac{1}{11}\sin 11(\omega t-\phi_1)+\ldots \end{pmatrix} \tag{3}$$

Which φ_1 is phase angle between source voltage and mean current.

Total harmonic distortion is defined as the ratio of the rms value of all harmonic components to the rms value of the fundamental frequency:

$$THD = \frac{(I_{1(rms)}^2 + I_{2(rms)}^2 + I_{3(rms)}^2 + \ldots + I_{n(rms)}^2)^{1/2}}{I_{1(rms)}} \tag{4}$$

For a p-pulse ideal rectifier, the harmonics being generated are of orders 5, 7, 11, 13, 17, 19 ..., i.e. those of orders 6k ± 1,

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where k is an integer.

In fig. 2 is shown input voltage and current, output voltage and tyristor voltage waveforms of three phase controlled rectifier when fire angle is 30.

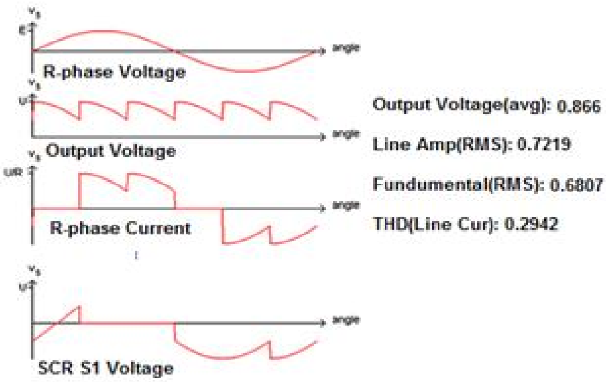


Figure 2. Various waveforms of three phase rectifier(α=30)

III. Methods of Harmonic analysis

Many research have been carried out to provide an accurate and easy method to obtain harmonic currents in rectifier. Harmonic interactions in thyristor bridges may be calculated either in the frequency domain or in the time domain or with statistical method. Any of them have advantage and disadvantage [cp14.pdf].

For example, The time domain method is easy to use and allow control of system operation under any number of different operating states. However they do not provide an analytical vision required for optimal design; besides frequency dependence cannot be accurately modeled. an alternative method for calculating the harmonic currents of a power converter uses the Fourier series and the switching functions. With a frequency domain model, the closed loop frequency responses can be established, which will facilitate the analysis of system stability and design optimization (paper4.pdf)

This paper proposed an accurate Statistical method to calculate the current harmonic components of controlled rectifiers.

IV. Simulation of three phase controlled rectifier

At the first, as shown in fig. 3, a three phase controlled rectifiers with inductive load is simulated with MATLAB software and then, input current waveforms and harmonic spectra is simulated for some of firing angle(α=30) Fig 4.

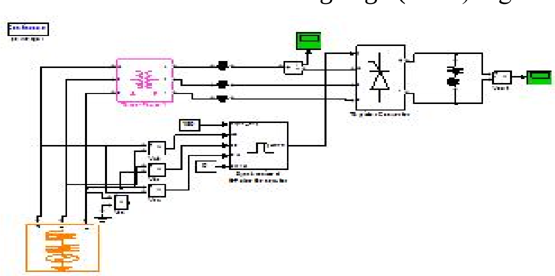


Figure 3. Simulation of three phase controlled rectifier with MATLAB

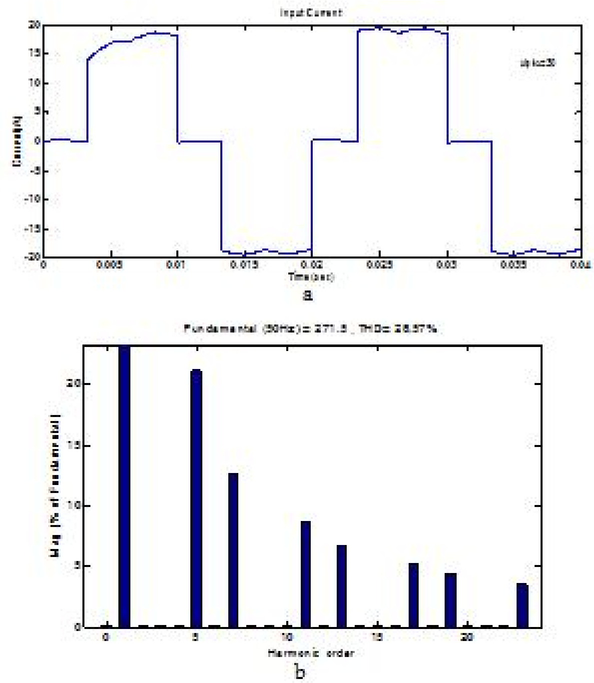


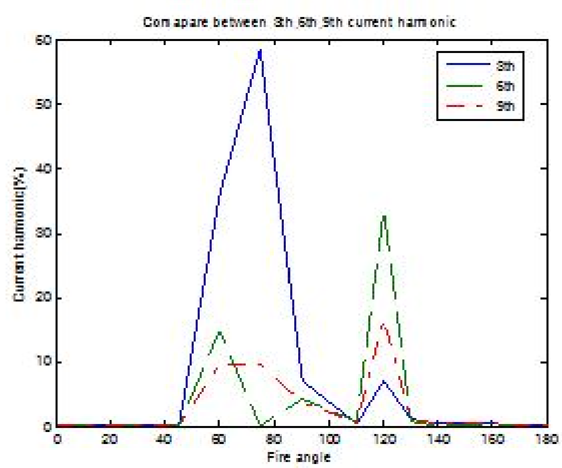
Figure 4. a) Input current waveform and b) spectra harmonic

The THD and Harmonic currents variations in terms of firing angle variations is shown in table I.

Table I: THD and Harmonic currents variations in terms of firing angle variations

α	0	15	30	45	60	90	110	130
THD	23.59	220.4	54.01	65.64	37.34	28.56	26.6	210.1
I_3/I_1	0.03	0.43	7.09	58.52	35.94	0.02	0.03	1.18
I_5/I_1	18.89	125.69	6.15	12.34	0.18	21.2	20.23	83.94
I_6/I_1	0.11	0.84	4.34	0.07	14.82	0.11	0.12	0.74
I_7/I_1	11.69	105.48	4.99	16.42	0.15	12.57	12.72	81.5
I_9/I_1	0.02	0.66	3.77	9.52	9.52	0.04	0.03	1.15
I_{11}/I_1	5.95	102.48	2.58	7.65	0.17	8.7	7.88	74.8

Compare between multiple and other current harmonics in Fig. 5.



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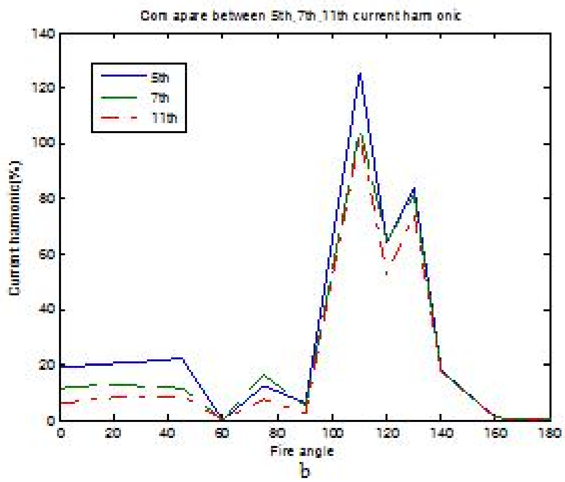

Figure 5. compare between a) multiple and b) other current harmonics

This rectifier is tested at laboratory. The obtained waveforms for input current with harmonic spectra for two fire angle is shown at fig.6.

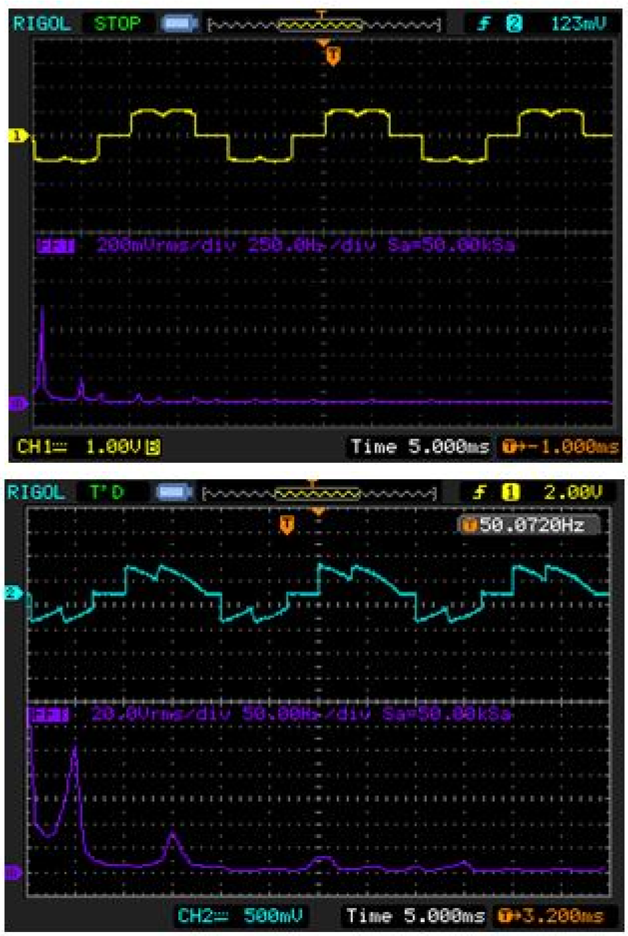

Figure 6. Obtained waveforms for input current at laboratory

According to obtained figures, can be observed that THD and harmonic currents is increased with increasing firing angles. The reason is that because thyristors are switched on with delay, so input current waveform Is out of Sinusoidal mode.

V. The influence of load variations on THD and Harmonic currents

In this section impact load variations on THD and harmonic current is shown. Load is resistive and inductive. It is clearly that increasing in resistive load increase THD and harmonic current. So inductor of load is changed.

In fig. 7 is shown input current waveforms and harmonic spectra is simulated for some of firing angle(α=30)

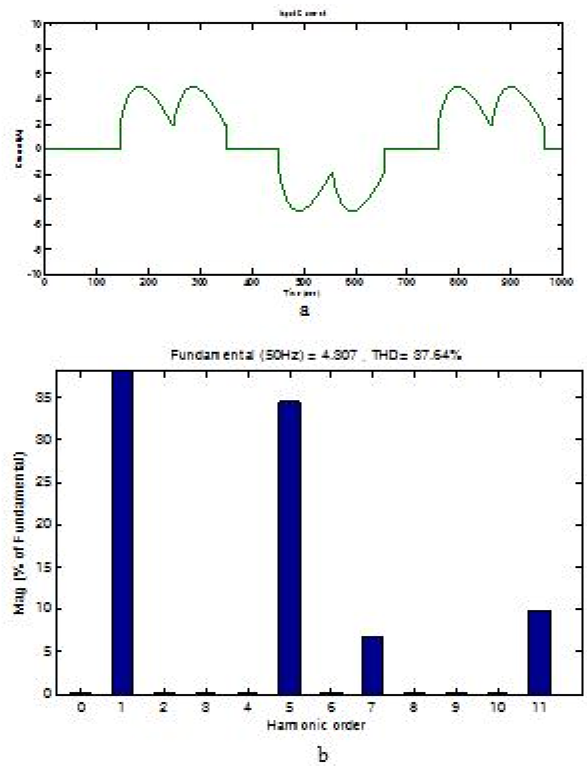

Figure 7. a) Input current waveform b) harmonic spectra(α=30)

In table II, The THD and Harmonic currents variations in terms of inductor variations is shown for some firing angle

Table II: THD and Harmonic currents variations in terms of inductor variations

alpha=30°								
L(mH)	0.19	0.38	1.9	3.8	5.7	7.6	11.4	15
THD	27.36	27.01	25.61	25.05	24.81	24.69	24.56	24.52
I_5/I_1	25.77	25.26	22.84	21.54	20.87	20.47	20.2	19.76
I_7/I_1	5.47	5.96	8.45	9.38	10.54	10.97	11.25	11.73
I_{11}/I_1	5.8	5.83	6.04	6.18	6.26	6.32	6.35	6.42
alpha=45°								
THD	23.59	220.4	54.01	65.64	37.34	28.56	26.6	210.1
I_5/I_1	18.89	125.69	6.15	12.34	0.18	21.2	20.23	83.94
I_7/I_1	11.69	105.48	4.99	16.42	0.15	12.57	12.72	81.5
I_{11}/I_1	5.95	102.48	2.58	7.65	0.17	8.7	7.88	74.8
alpha=60°								
THD	37.35	36.25	31.61	29.72	28.99	28.62	28.42	28.17
I_5/I_1	35.66	34.6	29.35	26.37	24.79	23.82	23.16	22.07
I_7/I_1	4.27	3.18	3.7	6.86	8.59	9.66	10.38	11.58
I_{11}/I_1	8.57	8.51	8.37	8.36	8.38	8.4	8.41	8.43

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The variation of THD in terms of inductance variations is shown in fig. 8

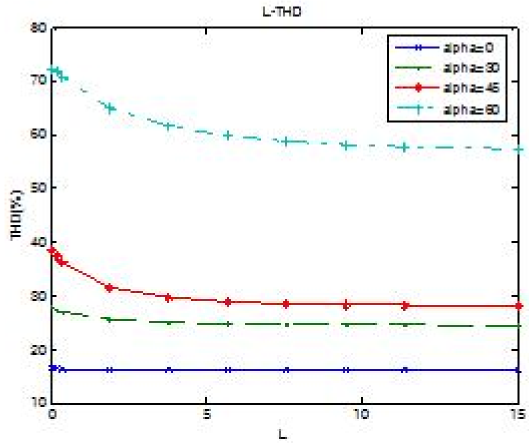

Figure 8. Variations of THD in terms of L

Also, according to tables variation of 5th harmonic current in terms of inductance variations is shown in fig.

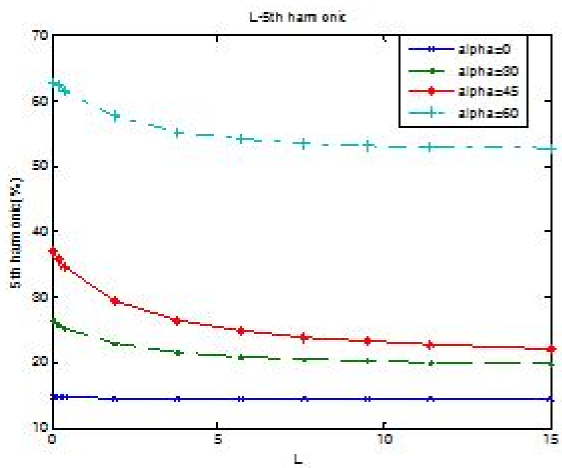

Figure 9. Variation of 5th harmonic current in terms of inductance variation

According to obtained results with the increasing induction load vitality, THD and current harmonic is increased. Because of decreases by rising load inductance. Because more inductor value causes output current waveform be smoother, therefore reduce harmonic currents.

Also a harmonic current database of rectiûers is obtained from table II. this database allows all harmonic currents of any three-phase rectiûer by inductive load to be easily calculated with interpolation and without numerical simulation tools.

Conclusions

This paper proposed an accurate Statistical method to calculate input current harmonic components of three phase controlled rectifier, and calculate THD and harmonic currents with accurate simulation in various firing angles, then study influence of load variations in terms of firing angle variations on harmonic currents. Finally a harmonic current database of rectiûers is obtained in terms of firing angle variations. According to obtained results, the THD and harmonic currents because of caused delay in firing tyristors is increased with increasing of firing angle while they decreases by rising load inductance. Because more inductor value causes output current waveform be smoother, therefore reduce harmonic currents.

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